Endogenous Health Investment, Saving and Growth

A theoretical study with an application to Chinese data

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Abstract

The idea behind this thesis stems from the existing abundance of empirical studies suggesting the strong correlation between longevity and economic growth. In a simple two period overlapping-generation framework, we establish a direct link between health investment and economic growth through endogenous survival rate. We find that health expenditure complements saving in equilibrium, thereby contributes to economic growth, which in turn leads to a further increase in health investment. The simulation with calibrated parameters also manifests the consistence between our results and the worldwide data as well as the fact of China.

Preface

First and foremost, I would like to express my utmost gratitude to my supervisor, Professor Michael Hoel, for his patient guidance, earnest help, constructive criticism and constant encouragement throughout my writing.

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Finally, I would like to dedicate this thesis to my husband Fei, for his understanding and full support during this long journey. Without your endless love, support and encouragement, this work would never be possible.

And I claim myself responsible for all the possible remaining errors.

Content

1. Introduction

The strong correlations between various measures of health and income per capital have led macro-economists to regard health as an essential part of any measure of well-being, although better health and longer life expectancy are mostly viewed as by-products of economic growth and development of a country[1]. The causal relationship between mortality and poverty is clearly bi-directional. On the one hand, people die young in poor country because they can't afford sanitation and medical care. On the other hand, they have less incentive to save if they expect themselves to die young and the economy fails to grow. By contrast, micro-economists have carefully looked at the determinants of the demand for health and established a bilateral mechanism between health and income: Health is analogous to a normal good, and higher income leads to an increase in the demand for health, but individual's health status also affects his or her income and earnings through different channels (Grossman 1972). These important results force economists to reconsider their analysis of the relationship between economic growth, health and longevity in the light of macroeconomic growth models that integrate the micro-foundations of health economics.

The present paper follows this goal and modifies the standard two-period overlapping-generation model developed by Diamond (1965) by incorporating an endogenous health investment. Since agents are alive only for a fraction in the second period of their life, they may optimally "control" this survival risk by incurring personal expenses on health. Agents face the following dilemma: longevity is desirable and necessary to enjoy the returns from past physical investments, but longer life is costly to acquire, which leads to lower physical investment and hence to a loss in future utility. For comparison, we use a benchmark model with an exogenous survival probability. Our main findings are as follows. Health investments are complementary to individual savings in equilibrium, which means agents will optimally choose to increase or decrease the savings and health

[1] Life expectancy is included in the Human Development Index.

investment at the same time. In equilibrium, health investment is a normal good which increases as income rises. Moreover, our findings are further supported by simulation with China's calibrated parameters. The results are consistent with empirical data, where countries with higher income spend more on health improvement and have on average longer life expectancy.

The rest of the paper is arranged as follows. A rough description of the health related data in China is given in the next section. In section 3, we present a brief literature review of some important empirical studies focusing on the linkage between health expenditure and economic growth, and of others touching upon economic growth utilizing exogenous and endogenous longevity respectively. We outline the theoretical model of this paper and discuss the equilibrium conditions in section 4. In section 5, we further look into how health expenditure relates to economic growth by a set of simulations under corresponding parameter assumptions. Concluding remarks are made in section 6.

2. Background

Following the amazing tenfold growth of GDP since 1978, total health expenditure in China has been experiencing a rapid growth over the past three decades. In 2004, China's total expenditure on health amounted to 747 billion Yuan, while the figure in 1978 being 11.02 billion Yuan. Total expenditure on health per capita rose from 11.45 Yuan to 583.90 Yuan during 1978-2004. Total expenditure on health per capita in 2004 was 51 times as high as the level in 1978. In US terms, China's total health expenditure was 917.03 billion dollars in 2004, with that in 1978 being 65.45 billion dollars; total expenditure on health per capita rose from 6.80 dollars to 61.61 dollars during 1978-2004 (see Table 2-1)[2]

This rapid growth of health expenditure is not only observed in absolute terms but also in the share of GDP. Table 2-1 shows an upward trend in total health expenditure expressed as a share of GDP in China. Over the period from 1978 to 2004, health expenditure in China increased from 3.04% to 5.55%, by one percentage point every 10 years in effect. In the year 2000, total health expenditure in China was 5.1% of GDP which exceeded the WHO's recommended lower limit of 5%, then in 2002 it accounted for 5.5 % of GDP, which was the world average share.

Table 2-1: China's Total Health Expenditure 1987-2004

Year	Health expenditure		Health expenditure as % of GDP	Health expenditure per capita	
	RMB 100million	Dollar 100 million		RMB (Yuan)	Dollar
1978	110.21	65.45	3.04	11.45	6.80

[2] All these data are reported in nominal price.

1979	126.19	81.15	3.12	12.94	8.32
1980	143.23	95.61	3.17	14.51	9.69
1981	160.12	93.91	3.29	16.00	9.38
1982	177.53	93.81	3.35	17.50	9.23
1983	207.42	104.99	3.50	20.14	10.19
1984	242.07	104.03	3.38	23.20	9.97
1985	279.00	95.01	3.11	26.36	8.98
1986	315.90	91.49	3.10	29.38	8.51
1987	379.58	101.98	3.17	34.73	9.33
1988	488.04	131.12	3.27	43.96	11.81
1989	615.50	163.48	3.64	54.61	14.50
1990	747.39	156.25	4.03	65.40	13.67
1991	893.49	163.09	4.13	77.14	14.49
1992	1096.86	198.90	4.12	93.61	16.98
1993	1377.78	239.11	3.98	116.33	20.18
1994	1761.24	204.35	3.77	146.95	17.05
1995	2155.13	258.07	3.69	177.93	21.31
1996	2709.42	325.88	3.99	221.38	26.63
1997	3196.71	385.62	4.29	258.58	31.19
1998	3678.72	444.34	4.70	294.86	35.62
1999	4047.50	488.93	4.93	321.78	38.87
2000	4586.63	544.05	5.13	361.88	43.71
2001	5025.93	607.22	5.16	393.80	47.58
2002	5790.03	686.80	5.42	442.55	53.47
2003	6584.10	795.47	5.62	509.50	61.61
2004	7590.29	917.03	5.55	583.90	70.54

Note: ① Health expenditure in this table is estimated, ② the data in this table are calculated at current prices.

Source: Ministry of Health of the People's Republic of China, China Health Yearbook 1987-2004, Abstract of China Health Statistics 1987-2003 http://www.moh.gov.cn

Parallel with the rising expenditures on health, there have been major improvements in health state in China. According to statistics from Ministry of Health in China (see Table 2-2), the average life expectancy of people in China has been raised from 35 years in the 1950s to approximately 72 years in 2004 (65 years in 1975, 67.9 years in1981, 68.5 years in 1990 and 71.4 years in 2000), higher than the average for the whole world (67 years) and for middle-income countries (69 years). At the same time, the mortality rate of Chinese infants declined from as high as 20 percent during some periods in 20th century to 2.5 percent at present. And the mortality rate of children over 5 years old decreased from 61.0 per 1000 to 29.9 per 1,000, while the maternal mortality rate decreased from 94.7 per 100,000 in 1991 to 51.3 per 100,000 in 2004. This improvement is not only characterized by better health indicators but also by the improved health infrastructure across the country. There are more than 300,000 hospitals and other medical institutions in 2005. Compared to 1990, China, in 2000, had 21.2% more beds in its hospitals and health centres, and 14.2% more trained health workers. Compared to 1995, in 2001, the number of health facilities, including clinics, rocketed by more than 70%. Just as is shown in Table 2-3, the general health status in China now equals that in a middle-income country.

Table 2-2 Selected Life Expectancy in China (Year)

Year	Data Source	Total	Male	Female
Before 1949		35.0	-	-
1957	70 cities, 1 county and 126 townships in 11 provinces	57.0	-	-
1973-1975	Retrospective Survey on Tumour Death in China	-	63.6	66.3
1981	The 3rd National Population Census	67.9	66.4	69.3
1990	The 4th National Population Census	68.6	66.8	70.5
2000	The 5th National Population Census	71.4	69.6	73.3

Source: Ministry of Health of China, http://www.moh.gov.cn

Table 2-3: Selected World Health Indicator (2000)

	Health expenditure % of GDP	Life expectancy at birth (years)	Child mortality (‰)	Maternal mortality (per 100,000)
World	5.5	67	81	-
China	**5.1**	**71**	**39**	**56**
Low income countries	4.5	63	121	550
Middle income countries	5.0	69	38	150
High income countries	9.7	77	7	10

Source: World Development Report 2002, World Bank

Despite the remarkable gains in key health conditions, expenditures on health may still be low and inefficient to meet China's development needs. By comparison, Table2-4 shows the trends in health expenditure of the OECD countries during the same period 1980-2004, which manifests that China's total health expenditure as share of GDP is lower than that in all these countries. In addition, it is lower than some developing countries (e.g. Cuba-7.3%, Brazil-7.6%, 2003) outside this organization. The income elasticity of health services spending was very small (1.09) compared with that in OECD countries (1.32~1.36). Therefore, the exceedance of demand for health services over the supply leads to a heavy medical burden for patients in China now (Peng, 2006)

Table 2-4: Different Performances of Health Care Systems in OECD Countries: Total Health Care Expenditure in GDP

	1985	1990	1995	2000	2001	2002	2003	2004
Australia	7.2	7.5	8.0	8.8	8.9	9.1	9.2	..

Austria	6.5	7.0	9.7 b	9.4	9.5	9.5	9.6	9.6
Belgium	7.0	7.2	8.2	8.6	8.7	8.9	10.1b	..
Canada	8.2	9.0	9.2	8.9	9.4	9.7	9.9	9.9 e
Czech Republic	..	4.7	7.0	6.7	7.0	7.2	7.5 b	7.3 e
Denmark	8.5	8.3	8.1	8.3	8.6	8.8	8.9 b	8.9 e
Finland	7.1	7.8	7.4	6.7	6.9	7.2	7.4	7.5
France	7.9	8.4	9.4	9.2	9.3	10.0b	10.4	10.5e
Germany	9.0	8.5	10.3	10.4	10.6	10.8	10.9	..
Greece	7.4 [2]	7.4	9.6	9.9 e	10.4e	10.3e	10.5e	10.0e
Hungary	..	7.1 [1]	7.4	7.1	7.3	7.7	8.3 e	8.3 e
Iceland	7.2	7.9	8.4	9.2	9.3	10.0	10.5	10.2e
Ireland	7.5	6.1 b	6.7	6.3	6.8	7.2	7.2	7.1
Italy	7.5 [3]	7.7	7.1	7.9	8.0	8.2	8.2	8.4
Japan	6.7	5.9	6.8 b	7.6	7.8	7.9	8.0 e	..
Korea	4.1	4.4	4.2	4.8	5.4	5.3	5.5	5.6
Luxembourg	5.2	5.4	5.6	5.8	6.4	6.8	7.7 b	8.0 e
Mexico	..	4.8	5.6	5.6	6.0	6.2	6.3	6.5
Netherlands	7.1	7.7	8.1	7.9	8.3	8.9	9.1 e	9.2 e
New Zealand	5.1	6.9	7.2	7.7	7.8	8.2	8.0	8.4
Norway	6.6	7.7	7.9	8.5	8.9	9.9	10.1	9.7
Poland	..	4.9	5.6	5.7	6.0	6.6 b	6.5	6.5
Portugal	6.0	6.2	8.2 b	9.4 b	9.3 e	9.5 e	9.8 e	10.0e
Slovak Republic	..	..	5.8 [2]	5.5	5.5	5.6	5.9	..
Spain	5.4	6.5	7.4	7.2	7.2	7.3	7.9 b	8.1 e
Sweden	8.6	8.3	8.1	8.4	8.7	9.1	9.3	9.1 e
Switzerland	7.8	8.3	9.7 b	10.4	10.9	11.1	11.5	11.6e
Turkey	2.2	3.6	3.4	6.6	7.5	7.4	7.6	7.7
United Kingdom	5.9	6.0	7.0	7.3	7.5	7.7	7.9 b	8.3 d
United States	10.1	11.9	13.3	13.3	14.0	14.7	15.2	15.3

Notes: ① -1, -2, -3, 1, 2, and 3 indicate that data refer to 1, 2 or 3 years back and forward respectively. ② For Germany, data up to 1990 refer to West Germany. ③ "b" means there is a break in the series for the given year; "e" means the data is an estimate.
Source: Organization for Economic Co-operation and Development

These facts attract several Chinese researchers' attention. Utilizing Granger causality test and VAR's impulse response and variance decompositions, Liu et al(2006) showed that the increase of total health expenditure and average health consumption lead to the growth of GDP and average disposable income, and then revealed that enhancing national health level would promote economic growth. Tan (2005) carried out a regression with respect to the health care expenditure and GDP during 1995-2002 using OLS and found a rather robust positive correlation between health care spending and GDP per capita: one percent increase in health care expenditure will lead to 0.7841 percent growth in GDP. Wang and Song (2004) found the health care investment is closely correlated to the regional economic growth and its contribution to the economic growth is most significant in western areas of China. Hu (2004) and Yin (2005) suggested that health expenditure doesn't merely indicate a simple consumption of health services, but rather constitutes an important type of investment and hence an impetus for economic development in the long term, and thus concluded that we should pay more attention to the growth of expenditure on health.

3. Literature Review

Grossman (1972) pointed out that health can be viewed as a durable capital stock that produces an output of healthy time. Individuals inherit an initial stock of health that depreciated with age and can be increased by investment. In recent years, a growing literature has attempted to explain the complex relationship between health investment and economic growth through many channels. Health capital can influence the pace of economic growth via its effect on many health related factors, including life expectancy, mortality rate, labour market participation, and labour productivity, investments in human capital, savings, fertility, and demographic structure.

The relationship between health investment, life expectancy and economic growth is a newly contested field[3]. Worldwide increases in longevity during the last few decades are well documented in numerous studies (e.g., World Bank, 1993). The following brief review of literatures in this field is organized in three categories: empirical evidence, theoretical works correlated to exogenous longevity and those correlated to endogenous longevity.

3.1 Empirical Evidence

A common empirical approach to study the effect of health capital on economic growth is to focus on a cross-section data of countries and to regress the growth rate of income per capita on the initial level of health (typically measured by life expectancy), controlling for the initial level of income and for other factors believed to influence steady-state income levels. From these cross-country growth regressions, researchers generally find that life expectancy, as the most important proxy for the health capital stock, has a

[3] The terms survival probability, survival rate, longevity and life expectancy are used interchangeably.

significant positive effect on the rate of economic growth. Bloom, Canning and Sevilla (2004) constructed a sample consisting of both developing and industrial countries observed every 10 years over1960-1990, and found that good health (life expectancy as the proxy) has a sizable, positive effect on economic growth. One year improvement in the life expectancy contributes to an increase of up to 4 percentage points in the long-run growth rate. Shastry and Weil (2003) found that adult mortality explains 19% of the log variance of income pre capita, which is almost one-third of the unexplained output variation across countries. Jamison, Lau and Wang (2004), using a sample of 53 countries, found that improvements in health (measured by the survival rate of males aged between 15 and 60) account for about 11 percent of growth during the period 1965-90. Zhang and Zhang (2005) conducted cross-section analyses using data from 76 countries based on their theoretical model, which held life expectancy exerting effect not only on growth but also on three growth determinants: education, fertility and saving. Some important organizations of developed countries found that high life expectancy exercises weaker effects, while in developing countries with low life expectancy and low per capita income but high birth rates, efforts on reducing mortality enjoy a good payoff.

This similar strong correlation is also observed in time series data. Fogel (1997) estimated that better health and nutrition alone may have contributed about 20-30% of British economic growth during 1780-1979. While the results of empirical growth equations are generally not completely-robust, Levine and Renelt (1992) and Sala-I-Martin (1997) found that initial life expectancy is a positive and significant predictor of economic growth during 1960-92 in more than 96 percent of the specifications. Boucekkine et al. (2003) estimated that a steady decline in adult mortality accounts for 70% of the growth acceleration during 1700-1820, the early modern period of Europe.

In addition, more studies based on the theoretical framework of Barro and Sala-I-Martin (1995) have found evidence of a positive, significant and sizable influence of life expectancy (or other health-related indicators) on the subsequent pace of economic growth (such as, Barro 1991, 1996, 1997; Barro and Lee 1994; Bhargava et al 2001; Easterly and Levine 1997; Gallup and Sachs 2000). All these studies differ substantially in terms of country samples, time frames, control variables, functional forms, data definitions and configurations, and estimation techniques. However, parameter estimates of the effects of life expectancy on economic growth have been reasonably comparable across studies.

3.2 Exogenous Longevity

As to the theoretical framework, when considering the issue of longevity, theorists always assume that an individual's expected lifetime is independent of his decisions. Following Yaari (1965), many researchers have modelled this as a parametric probability of surviving from one period to the next. Incorporating this exogenous variable, analyses proposed by Ehrlich et al (1999), Zhang et al (2001), Zhang and Zhang (2005) demonstrate a positive correlation between life expectancy and economic development.

Ehrlich et al (1999) developed an overlapping-generation model of endogenous growth, in which human capital is the engine of growth and generations are linked through material and emotional interdependencies within the family. Agents are both consumers and producers who invest in their children to achieve both old-age support and emotional gratification, and material support from children is determined through self-enforcing implicit contracts. Their model produces a theory of the "demographic transition" linking longevity, fertility, and economic growth. The family is viewed as a mutual insurance mechanism that links over-lapping generations through optimal intra-family transfers, or inter-generational trade, as well as through related altruistic sentiments. With a limit in lifespan, the parents' motive of investment in their children is identified to be a combination of self-interest and a form of altruism. Thus, despite that population ageing may raise the economic growth; an increase in young-age longevity is likely to produce a bigger increase in growth rate and reduction in fertility rate.

Zhang et al (2001) examined the effect of longevity on growth in a model with imperfect capital markets and public education. Human capital enters production function in addition to physical capital. They showed that the decline in mortality affects growth positively or negatively in three ways. Corresponding to empirical evidences, the net effect of a decline in mortality is to raise the growth rate in Third World societies; however, starting from a low mortality rate in most industrial populations, the net effect of a further decline in mortality is to reduce the growth rate. These findings justify the concerns about the possible adverse growth effect of rising longevity in developed countries, such as the empirical evidences found by Kelley and Schmidt (1995).

In another paper by Zhang and Zhang (2005), a growth model was constructed where agents with uncertain survival choose schooling time, life-cycle consumption and the number of children. Both leisure and the number of children are incorporated in a logarithmic utility function, which captures a trade-off between the cost of children-bearing and the returns from the offspring. The model shows that rising longevity reduces fertility but raises saving, schooling time and the economic growth rate at a diminishing rate.

3.3 Endogenous Longevity

While yielding important insights, all of the above analyses are limited in that agents are not allowed to choose life expectancy by themselves. Clearly, this is not true in the real economy and it is plausible that life expectancy may change with changes in government policies and in other various aspects of social environment. And the endogenous longevity is always associated with multiple development regimes.

In the analytical framework by Blackburn and Issa (2002), agents mature safely through two periods of life and face an endogenous probability of surviving for a third period. They compare different characteristics of exogenous and endogenous life expectancy. An exogenous increase in life expectancy leads agents to increase their savings during middle-age so as to finance consumption during old-age, which is converted into an increase in capital accumulation and growth. When an endogenous life expectancy is supported by a constant proportional income tax, the increase in life expectancy feeds back on the economic growth process. This produces multiple development regimes such that limiting outcomes depend critically on parameters values and initial conditions. An economy that starts up with poor situation may be destined to remain poor (so called poverty trap), unless there are major changes in circumstances which allow the threshold to be eliminated.

With the same analytical mechanism as Blackburn and Issa (2002), Chakraborty (2004) incorporated investment in education in his model. Both health improvement and schooling are supported by public expenditures. By assuming a logarithmic utility shape, he showed that the dynamic system may have multiple equilibria depending crucially on the output share of capital. His results are consistent with those of Blackburn and Issa (2002). High-mortality societies do not grow fast since lower longevity discourages saving and investment such as education. When human capital drives economic growth, countries differing only in health capital do not converge to similar living standards. The low-mortality society always invests more intensively in skill at a higher rate and thereby augments its health capital at a faster pace. As a result, it consistently enjoys a higher growth rate along its saddle-path than the country with higher mortality risks.

Finlay (2005) generalized the environment and broadened the scope of the results in Chakraborty (2004). He suggested that economic growth is driven by human capital accumulation by way of investment in schooling and this investment is necessary for an economy to get out of the poverty trap. However, investment in schooling is concurrent to investment in health, as the latter increases life expectancy and thus augments the possibility to enjoy the realized returns to the former. Positive investment in health, however, is only possible when the individual’s income exceeds a stated threshold. Furthermore, investment in schooling will occur when income reaches a second, higher, income threshold determined by the level of human capital. To reach these thresholds, it is advised that donor countries offer aid in the form of improvements in skill level rather than in the baseline level of health, as it is private investment in health that is required to encourage investment in education and not exogenously given levels.

Instead of assuming that health expenditure is only financed by public sector, Bhattacharya and Qiao (2005) used a two-period overlapping-generation model to capture the relationship between public and private health expenditures. Their research differs from others in that the improvement in longevity is jointly supported by private part and public sector, where the survival probability function enables health production to be more efficiently stimulated by public health expenditure. They simplified the theoretical analysis by concerning the old-age utility only. As in other neoclassical growth models, chaotic dynamics are found in their model, and the optimal saving is independent of its return which implies that the modelled economy would not produce any endogenous fluctuations.

In this paper, we will examine the relationship between health capital, life expectancy and economic performance in a very simple two-period overlapping-generation model. We allow the individual to investment in their own health capital, which endogenously influences their life expectancy and hence exerts an impact on economic growth. In doing so, we intend to explore some macro-implications of health capital in the process of economic development.

4. The Environment

We now consider a simple two-period overlapping-generation model with discrete time. In each time period, a constant number (normalized to unity) of young agents are born. Each agent within any generation is identical ex ante. Each generation is considered to live for two periods: the “young” age and the “old “age. Agents born in random period t live in youth for sure, but survive into the old age only with a probability π_t which is determined by their health stock.

In our model, we will follow Grossman’s view (1972) that health can be viewed as a durable capital stock and can be increased by investment. Given a health production function, agents here are assumed to be able to produce health stock by purposeful health investment. Different from conventional conception that only includes spending on medical products and services, health expenditure in our model will be broadly defined as all spending and activities related to improving the health stock of the agent. Assume that the probability for a generation t agent to survive to the second period depends upon her health stock, h_t . The survival probability function therefore can be denoted as $\pi_t = \pi(h_t)$, which is an increasing function in health stock. It can be thought as a kind of production function which makes use of resources to “produce” chances of surviving into the old age. Thus, this function can be expected to exhibit the usual properties of a normal production function. For analytical simplicity, we assume the following conditions: $0 < \pi(\cdot) < 1$, $\pi'(\cdot) > 0$, $\pi''(\cdot) < 0$, and Inada condition $\lim_{m \to 0} \pi'(h) = +\infty$ and $\lim_{m \to \infty} \pi'(h) = 0$. Finally, the health stock of an agent will drop to zero and the agent dies by the end of the second period with certainty.

4.1 The Agent's Problem

When considering the probability of surviving into the second period π_t, individuals born in period t maximize their expected lifetime utility over consumption in the first period of life c_t, and that in the second period c_{t+1}. For an individual agent of generation t, his expected life-time utility can be expressed as:

$$U = \tilde{U}(c_t, c_{t+1}, \pi_t)$$

Here, $U' > 0, U'' < 0$. In order to develop a direct linkage between health expenditure and economic growth, we follow several literatures (e.g. Blackburn and Issa 2002) and consider the following special case for the above general expected lifetime utility:

$$U(c_t, c_{t+1}, \pi_t) = u(c_t) + \beta \pi_t u(c_{t+1})$$

Agent's preferences are identical for all generations. The preferences in these two periods are given by a strictly increasing and concave utility function $u(c)$, satisfying the Inada condition at zero. The utility function from the second-period consumption satisfies an additional condition $u(c_{t+1}) \geq 0$ in case that the agents prefer death to surviving. The parameter β is utility discount factor, which is not greater than 1 and indicates the substitution relationship between different cohorts' utility. And the survival probability is always incorporated with β when demographic impact is considered, such as in the well-known work by Imrohorolu, Aye; Imrohorolu, Selahattin; Joines, Douglas H (1998). To simplify the analysis, we set $\beta = 1$ in our model hence the expected lifetime utility takes the form[4]:

$$U(c_t, c_{t+1}, \pi_t) = u(c_t) + \pi_t u(c_{t+1}) \qquad (1)$$

All agents in each period are endowed with one unit of labour when young, which is then supplied inelastically in the labour market, and 0 when old. By supplying labour, in the first period of his life, an agent who is born in period t gets a market wage rate w_t.

Having earned w_t when young, the agent only consumes part of this wage in the first

[4] Entire insight will goes through if a discount factor smaller than 1 is taken account into the agent's expected lifetime utility.

period c_t, saves some amount to finance the consumption in the next period s_t, and invests the rest on the health stock h_t.

If an agent survives to the second period, then she has no job any longer but finances her consumption entirely by savings. As in other models of uncertain lifetimes, we need to deal with the subtle issue of how to treat the retirement savings left by those agents who do not survive to old-age. As far as the present analysis is concerned, it makes no essential difference as to whether one assumes these savings to be merely wasted (e.g., Ehrlich and Lui 1991), or to be distributed among the surviving population of savers through actuarially fair annuity markets (e.g. Zhang and Zhang 2001, Yaari 1995 and Blanchard 1985). We just follow the latter in assuming a perfect annuities market to reallocate the total wealth of those who die before reaching their old age to the remaining survivors within the same generation. Quatitatively similar results can be reached as long as transfers are made to surviving members of the same cohort. However, if these assets are transferred to the offspring of the deceased as accidental bequests, it will result in asymptotic growth (Fuster, 1999). To simplify our further analysis, we assume that these wealth are equally transferred in a form of lump-sum to the alive:

$$\tau_t = \frac{(1-\pi_t)s_t(1+r_{t+1})}{\pi_t} \tag{2}$$

Therefore, a generation t agent maximizes her expected lifetime utility given in equation (2), subject to the following period budget constraints:

$$c_t = w_t - s_t - h_t \tag{3}$$

$$c_{t+1} = s_t(1+r_{t+1}) + \tau_t \tag{4}$$

$$\pi_t = \pi(h_t) \tag{5}$$

Therefore, taking w_t, r_t and τ_t as given[5], for the maximization problem of generation t agents, the first order conditions with respect to s_t and h_t are respectively:

$$u'(c_t) = \pi(h_t)u'(c_{t+1})(1+r_{t+1}) \tag{6}$$

[5] Since the transfer is assumed to be in lump sum, agents view τ_t as a number that is independent of their individual savings decisions because they can't expect the amount of survival probability.

$$u'(c_t) = \pi'(h_t)u(c_{t+1}) \quad (7)$$

Actually, Equation (6) is the so called Euler Equation, which means that the marginal rate of substitution between current and future consumption equals the expected return on savings. In other words, the household chooses saving so as to smooth consumption over his life-cycle. And Equation (7) shows the trade-off between the marginal cost and marginal benefit of health expenditure. By investing in health stock, the agent decreases the current consumption in exchange for an increase in the survival probability in the second period.

4.2 The Firm's Problem

The firm's problem in this model is entirely standard. There are many competitive firms in this economy, and the number is normalized to unity. As in the standard neoclassical model, production is carried out using capital input K_t and labour input L_t at time t, through constant-return-to-scale technology $F(K_t, L_t)$ that satisfies the usual Inada conditions. The aggregate capital stock is assumed to depreciate at the rate δ. In any period t, each firm takes $\{w_t, r_t\}$ as given and solves the following problem:

$$\pi_t = F(K_t, L_t) - w_t L_t - (r_t + \delta)K_t \quad (8)$$

We assume that capital is depreciated completely in every period, which means δ =1. If k denotes the capital stock per worker, let $f(k) \equiv F(k,1)$ represent the intensive-form production function. Perfect competition in the final good market implies that both labour and capital are paid according their marginal products respectively, so that prices are given in intensive form:

$$r_{t+1} + 1 = f'(k_{t+1}) \quad (9)$$

$$w_t = f(k_t) - k_t f'(k_t) \quad (10)$$

We assume that the production technology is represented by a Cobb-Douglas product function:

$$f(k) = Ak^{\alpha}. \quad (11)$$

Here $A > 0$, and $\alpha \in (0,1)$. Thus, the firm's problem leads to the following standard first order condition for this product function:

$$w_t = (1-\alpha)Ak_t^{\alpha} \tag{12}$$

$$r_{t+1} + 1 = \alpha Ak_{k+1}^{\alpha-1} \tag{13}$$

Given the balance condition of capital stock $k_{t+1} = k_t(1-\delta) + s_t$, it yields:

$$k_{t+1} = s_t \tag{14}$$

Finally, the initial capital stock is $k_0 > 0$.

4.3 General Equilibrium

Combining the first order conditions of agents, we obtain:

$$\pi'(h_t)u(c_{t+1}) = \pi(h_t)u'(c_{t+1})(1+r_{t+1}) \tag{15}$$

This gives the condition on how to allocate a marginal dollar, savings versus health expenditure. If a marginal dollar is allocated towards savings, the agent gains marginal utility from the expected gross return of the dollar. On the other hand, if the same dollar is allocated towards health care expenditure, it increases the chance of actually enjoying future consumption by $\pi'(h_t)$. Thus, in equilibrium an agent will allocate the marginal dollar towards health expenditure such that the utility gain from health creation just equals the utility loss from having less expected second-period income.

Therefore, a competitive equilibrium path of this overlapping-generation economy can be represented by a sequence of aggregate capital stocks, individual saving and health investment, $\{k_t, s_t, h_t\}_{t=0}^{+\infty}$, such that they satisfy the first order conditions (6) and (7), in addition to equations (2),(3)-(5), (9), (10) and (14). Then the first-period and second-period consumptions can be expressed as:

$$c_t = f(k_t) - k_t f'(k_t) - s_t - h_t \tag{16}$$

$$c_{t+1} = \frac{s_t f'(s_t)}{\pi(h_t)} \tag{17}$$

Meanwhile, in equilibrium, the sequence of wage rate, the net return of capital and individual saving are given by (9), (10) and (14), respectively.

In equilibrium, with the consumption at old age (17) and the net return for next period capital (9) and (14), equation (15) gives:

$$\pi'(h_t)u(\frac{s_t f'(s_t)}{\pi(h_t)}) = \pi(h_t)u'(\frac{s_t f'(s_t)}{\pi(h_t)}) f'(s_t) \tag{18}$$

The above equation indicates the relationship between health investment and individual savings. For a Cobb-Douglas production technology, the total return of capital $kf'(k)$ increases as the amount of capital in production increases[6].With this condition, we can prove from equation (15) that the amount of saving s_t and the health investment h_t are strictly positively related in equilibrium (see Appendix 1).This means that savings/capital and health investment are complements along the equilibrium path despite the direct competition for resources. For the agents' part, there are two motives to save more when health investment increases: on the one hand, a higher health investment raises the agent's survival chance and his life expectancy, so that he has more incentive to save for the old-age income. On the other hand, as health investment becomes higher, its marginal benefit diminishes and saving becomes a more attractive alternative.

To some extent, the above analysis indicates the possible relationship between health investments and economic growth, because health investment will lead to more savings and hence growth. In order to examine the role of health investment in the economic development more closely, we assume the expected utility function for the agents in equation (1) is a Constant Relative Risk Aversion (CRRA) utility function:

$$u(c) = \frac{c^{1-\gamma}}{1-\gamma} \tag{19}$$

The utility function form is quite standard, however, we assume a restriction on the relative risk aversion coefficient ($0 < \gamma < 1$) to avoid the agents preferring death to

[6] The total return of capital in standard Cobb-Douglas production function is $kf'(k) = k \cdot A\alpha k^{\alpha-1} = \alpha f(k)$. Thus, $f'(k) + kf''(k) > 0$ holds because $d(kf'(k))/dk = \alpha f'(k) > 0$.

surviving. A value of $\gamma > 1$ will yield a negative utility function in consumption, hence $\gamma < 1$ is assumed so that consumption has the intuitive effect of positive expected utility even at a very low level.[7]

Following Chakraborty (2004), we assume an increasing and concave survival probability function:

$$\pi(h_t) = \pi_0 + \bar{\pi}\sqrt{\frac{h_t}{1+h_t}} \tag{20}$$

Here, π_o and $\bar{\pi} \in (0,1)$, $\pi_0 + \bar{\pi} \leq 1$. In addition, this function consists of two parts which are related to two kinds of health capital respectively: the inherent health capital and supplementary health investment. This is in line with Finlay (2005), who takes the inherent health situation as an exogenously determined value, and health investments include public health infrastructures such as a closed sewerage system and access to clean water as well as private investments such as private health insurance and physical exercises. The first part π_0 represents the survival probability of an agent if he spends nothing on health services, which actually can be regarded as everyone's inherent health capital; the second part of this function $\bar{\pi}\sqrt{\frac{h_t}{1+h_t}}$ represents supplementary chance of survival which increases with the consumption of health services. And $\bar{\pi}$ can be interpreted as measuring the state of medical technology: An improvement in $\bar{\pi}$ not only makes health production more effective, but also raises the maximum amount of life extension achieved by health investment. In addition, $\pi'(0) = +\infty$ which means that the spending on the health services will be positive in equilibrium and the survival probability will go to $\pi_0 + \bar{\pi}$ as the health investment goes to infinity.

Given the above functions, we obtain an explicit form of equation (15):

[7] In this model of uncertainty, expected utility is interpreted as cardinal utility and not ordinal utility, hence the value of utility matters. Moreover, in this OLG model the implicit expected utility of death is zero, so when expected utility of consumption is negative then the individual will always prefer dying to living no matter how high consumption is. Therefore, if $\gamma > 1$, a strictly positive investment in health will never occur. (Finlay, 2006)

$$\pi(h_t)(1+r_{t+1})(c_{t+1})^{-\gamma} = \pi'(h_t)\frac{(c_{t+1})^{1-\gamma}}{1-\gamma} \tag{21}$$

Equation (9), (14) and (17), (21) give:

$$s_t = s(h_t) = (1-\gamma)\frac{\pi(h_t)^2}{\pi'(h_t)} \tag{22}$$

This equation is the explicit form of equation (18), which indicates the complementary relationship between health investment and saving in equilibrium. Given $\pi(h_t)$ is increasing and concave and $\gamma < 1$, $s(h_t)$ is an increasing function with respect to health investment. This confirms the positive relationship between savings and health investment.

We further investigate how health investment is linked to economic growth with this given explicit form. With the utility function given in (19), inserting equation (10), (16) and (17) into the first condition (6), we obtain:

$$\frac{1}{\left[f(k_t)-k_t f'(k_t)-s_t-h_t\right]^{\gamma}} = \pi(h_t)^{1+\gamma}\frac{f'(s_t)^{1-\gamma}}{s_t^{\gamma}} \tag{23}$$

The parameter α in production function represents the share of capital income in total output. Several empirical works have indicated that the value of α ranges from 0.25 to 0.4 (e.g. Mankiw, Romer, and Weil 1992)[8], so that $\alpha < 1/2$ is a reasonable restriction for α. Under this condition, we can prove that health investment is increasing with respect to capital labour ratio k_t (see Appendix 2). Given the positive relationship between health investment and individual savings, the increase in capital k_t will lead to the growth of h_t and s_t, which implies an increase in k_{t+1}. It means, an increase in the capital stock allows the economy to invest more in health, which leads to more saving for future capital stock. Finally, these dynamic evolutions of variables make economy converge to the steady state. In this model, the equilibrium dynamics are determined by the initial per-capita capital stock k_0, (14), (22) and (23). The dynamics of this economy

[8] In our model, the agents live two periods (always assumed 30 years or longer per period).The values are reported in these literatures without our special assumption that Capital is depreciated completely in every period. However, this value range is still reasonable, because we can expect the complete depreciation of capital after 3o years if the physical capital is normally depreciated.

converge to a unique steady state (See Appendix 3) characterized by $s_t = k_t = k = s$ and $h_t = h$.

Income increases with the accumulation of capital because of the positive relationship indicated in equation (10). This implies that health investment is indeed a normal good, which is in line with Grossman's view mentioned in the introduction part. Thus, economic growth will raise the accumulation of health capital; richer countries spend more on health improvement and have a higher average life expectancy.

4.4 The Economy without Health Investment

We investigate the role of health expenditure in economic growth in our model; however, health investment is typically omitted in most of the economic growth models. We can get better understanding about the impact of such omission in conventional models, as well as the effect of health care on growth, by comparing our model with a benchmark model. This benchmark model is identical with our model except that the former doesn't include the health care sector, which means that health investment is zero ($h_t = 0$) and survival probability π_t is equal to π_0.

In this benchmark economy, the firm's problem is the same as that in our model; however, the agent faces a new optimal problem:

$$U_0(c_t, c_{t+1}, \pi_0) = u(c_t) + \pi_0 u(c_{t+1}) \tag{24}$$

Subject to:

$$c_t = w_t - s_t \tag{25}$$

$$c_{t+1} = s_t(1 + r_{t+1}) + \tau_0 \tag{26}$$

Here, $\tau_0 = \dfrac{(1-\pi_0)s_t(1+r_{t+1})}{\pi_0}$ is the wealth transferred to the alive when $\pi_t = \pi_0$. The maximization problem of generation t agents gives the following first order condition with respect to s_t:

$$u'(c_t) = \pi_0 u'(c_{t+1})(1 + r_{t+1}) \tag{27}$$

Following the similar steps in our model with health investment, we get the competitive equilibrium path of this benchmark economy. It is characterized by a sequence of $\{s_t, k_t\}_{t=0}^{+\infty}$ that satisfies the first order conditions (27), and equations (24), (25), (26), (9), (10) and (14). Now, the first-period and second-period consumptions can be expressed as:

$$c_t = f(k_t) - k_t f'(k_t) - s_t \tag{28}$$

$$c_{t+1} = \frac{s_t f'(s_t)}{\pi_0} \tag{29}$$

Meanwhile, in equilibrium, the sequence of wage rate, the net return of capital and individual saving are given by (9), (10) and (14), respectively.

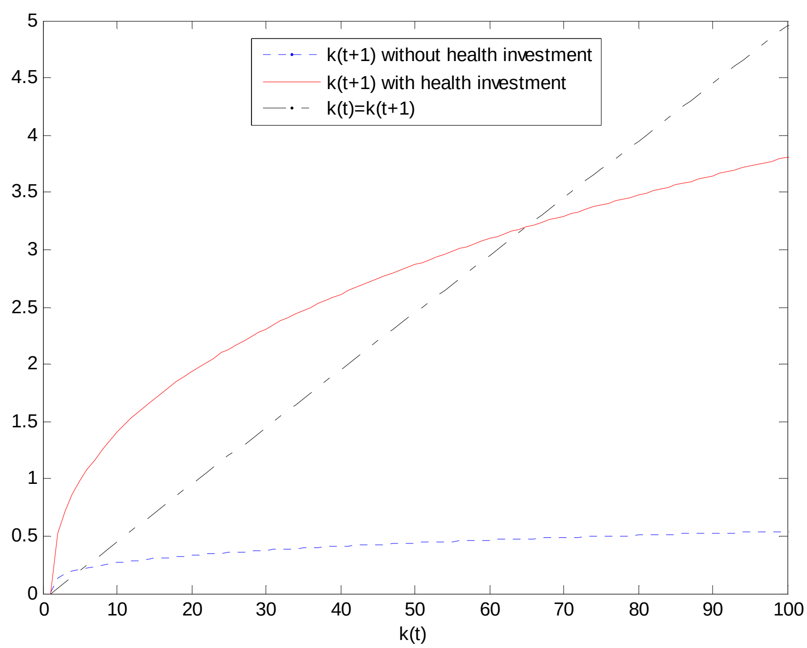
Therefore, with the utility function given in equation (19), the steady state of this benchmark economy can be expressed as:

$$\frac{1}{\left[f(k_t) - k_t f'(k_t) - s_t\right]^{\gamma}} = \pi_0^{1+\gamma} \frac{f'(s_t)^{1-\gamma}}{s_t^{y}} \tag{30}$$

The equilibrium dynamics are determined by the initial per-capita capital stock k_0, (14), and (30). This benchmark economy also has a unique steady state (See Appendix 3).

With reasonable parameters ($\pi_0 = 0.2, \bar{\pi} = 0.6, \gamma = 0.5, \alpha = 0.4$, discussed in detail in the next section), we simulate the transition paths of capital-labor ratio for the cases with and without health investment (see Figure 4-1). Considering the two economies that differ only in their health capitals, we use Figure 4-1 to describe the steady states in these two economies when the output share of capital is less than 1/2. Starting with the same level of initial capital stock, the economy with health investment will enjoy higher survival rate. The dynamic behavior of the society with better health status is described by the upper line, whereas the lower line applies to the high-mortality economy omitting health investment.These two curves follow from equations (22)and (23) with endogenous survival rate and from equation (30) with exogenous survival rate. Along the transition path, the capital-labor ratio in the economy with health investment is higher than that in the benchmark economy without health investment. We calculated the saving level in the two cases numerically for a given capital stock, saving in former case is higher than that in the latter case. In the economy with better health, agents expect themselves to live into the second period with higher probability and to enjoy a longer life expectancy, and thus save more for the future life. This length-of-life effect leads to higher capital stock which in turn brings more health investment. In the counterpart economy, higher mortality rate will make individuals effectively impatient, which depressing saving, capital accumulation and health investment further. From Figure 4-1, obviously, the upper one converges to a higher steady-state capital-labor ratio, because expenditure on health leads to faster capital accumulation. Despite that health investment diverts resource from productive use, it extends life expectancy which in turn leads to higher capital accumulation and hence economic growth.

Figure 4-1: Steady states with and without health investment



5. Simulation Analysis

In this section, using the calibrated parameters of China, we run MATLAB 7.0 to simulate these two economies and to compare their steady states. Furthermore, we carry out sensitivity test with respect to alternative parameters.

5.1 Calibration

Parameters:

A	π_0	$\bar{\pi}$	α	γ
10	0.2	0.6	0.4	0.5

Li et al. (1993) estimated the capital income share in China to be 0.464 for the reform period. In our base simulation, the value of labour share is taken from the study of Wang (2003), in which labour income is taken to be the average labour remuneration across China's 28 provinces and the share calculated thereby remains fairly steady at this level over the entire reform period of 1978-99. Many literatures (e.g. Mankiw 1981, Mankiw et al 1985, and Hansen and Singleton 1983) show that the inter-temporal substitution rate (the inverse of the relative risk aversion coefficient γ) ranges from 1 to 10. In their paper on China's optimal saving ratio, Yuan and Song (2000) took this value to be 3, 5 and 7. We select $\gamma = 0.5$ in our base case simulation. Other values will be used in sensitivity analysis.

We assume survival probability depends on both inherent health capital and supplementary health investment. The inherent survival probability can be assumed to be the probability of surviving to age 65 (retirement age) before People's Republic of China was founded. In fact, during that period, there was a lack of any formal health investment since people were even short of adequate food for survival due to warfare, and life expectancy at birth was only 35 (see Table 2-2). According to the World Bank

Development Indicators 2001, the survival probability in some poorest African countries ranges from 0.2 to 0.4 (for instance, it is 0.22 in Sierra Leone), and their life expectancy at birth ranges from 35 to 40 years. Since we lack related data of China in that period, we could reasonably choose $\pi_0 = 0.2$ as an approximation in the base case, and other values will also be tested. In addition, given that survival probability to age 65 is 0.73 in China, with the same argument, $\bar{\pi} = 0.6$ seems to be a reasonable starting point which implies that the medical technology allows a survival probability to the retirement age up to 0.8. Therefore, we choose the model without health investment as the benchmark with $\pi_0 = 0.2$, which is parallel to the case before the founding of People's Republic of China.

Our simulation results concentrate mainly on seven variables. The medical technology efficiency parameter $\bar{\pi}$ is used as a proxy to study whether incorporating endogenous health investment leads to higher steady state income per capita and welfare, compared with the benchmark model where the role of health investment in reducing mortality is absent.

5.2 Health Investment and Growth

Simulation results for health investment h are summarized in Table 5-2. The second, third and fourth columns simply show the steady state values of health investment and its proportion to income and GDP, expressed by h, h/w and $h/f(k)$ respectively, followed by the survival rate $\pi(h)$ and capital stock k in the fifth and sixth columns. Since the young agents are the only workers in the economy, GDP per worker is simply measured by $f(k)$ in the seventh column. GDP per capita is then measured as $f(k)$ divided by the total population including the old agents, $1+\pi(h)$, in the eighth column. In the last column, welfare level is measured by the stationary lifetime utility of agents alive in the steady state $u(c_1)+\pi(h)u(c_2)$, where c_1 and c_2 are consumption levels of an agent at young age and old age in the steady state.

One immediate impression from Table 5-2 is that the steady state values of capital stock, GDP per worker, GDP per capita and welfare are obviously higher in our model with endogenous health investment than in the benchmark. Even though a higher steady state capital stock k is associated with a greater health investment h, we should notice that there is no direct causality between h and GDP per capita as well as welfare in our theoretical model. However, this conclusion is robust with respect to the state of medical technology and a wide range of other parameter values (see sensitivity analysis). These results provide a convincing support to the hypothesis that health expenditures promote economic growth and welfare. In other words, it suggests that the conventional empirical studies about economic growth of China that omit health investment as an explicit choice variable tend to either underestimate growth or overestimate the roles of other factors in production. Quantitatively, Table 5-2 shows that the effects of incorporating health investment into the benchmark model are economically significant. We can see that, with specific level of medical technology $\bar{\pi}$, investment in health stock could potentially improve both the steady state GDP per capita and welfare by as much as around 100% over the benchmark levels.

Furthermore, Table 5-2 exhibits a positive association between health expenditure to GDP ratio and medical technology. The observed cross-country pattern in health expenditure in Table 2-3 might be partially explained by different availability levels of medical technology among different country groups. Table 2-3 reveals that the difference in health expenditure to GDP ratio between low and middle income countries is much smaller (4.5% and 5.0% respectively) than that between middle and high income countries (9.7%). Matching our simulated health expenditure shares in Table 5-2 with the data in Table 2-3 requires a $\bar{\pi}$ value of roughly 0.16, 0.18, and 0.8 for low income, middle income and high income countries respectively. This implication seems to fit quite well with the observed fact that, while some rough medical technology is basically available all over the world (such as China), more advanced medical innovation are mostly implemented in high income countries.

We also see the effects of medical technology in Table 5-2. The enhancement of medical technology, i.e. the increase in $\bar{\pi}$, leads to increases in all variables in Table 5-2. In a research report, using a stochastic, multi-period overlapping-generation model as the analytical vehicle, Suen (2005) proposed that improvements in medical treatment and rising incomes can explain all of the increase in medical spending and more than 60% of the increase in life expectancy at age 25 during the second half of the twentieth century. Consequently, the economic impact of improving medical technology in our model is quite significant. For instance, raising $\bar{\pi}$ from 0.1 to 0.8 can bring about an increase of 86% in GDP per capita and of 76% in welfare. Particularly, in Table 5-2, the $\bar{\pi}$ values of 0.1 and 0.2 correspond to the health expenditure to GDP ratios of China during the early period of reform and the recent period (see Table 2-1)[9]. We see that the simulated steady state GDP per capita and welfare are improved by as much as 19% and 13% respectively in the wake of a small-extent enhancement in medical technology. Naturally, the power of continuous improvement in medical technology declines due to the diminishing marginal returns in both goods production and health production. We find that, an increase of $\bar{\pi}$ from 0.1 to 0.2 leads to about 33% rise in survival probability and 19% rise in GDP per capita (as is mentioned above in China case), while an increase of $\bar{\pi}$ from 0.7 to 0.8 only leads to about 12% rise in survival probability and 3.0% rise in GDP per capita. Intuitively, medical advancement entails greater incentives to spend on health improvement, but the survival probability function shares the common features of other production functions, namely, diminishing marginal returns with respect to factors.

[9] Note that the morale of comparing steady state GDP per capita between these two periods is to emphasize the role of improvement in medical technology (in reality, the GDP per capita is increased by roughly 6 times from 1980 according to China National Statistical Bureau). This is the same with other comparisons among low income, middle income and high income country groups.

Table 5-2: Lump sum health investment

Parameters: $\pi_0 = 0.2, \alpha = 0.4, \gamma = 0.5, A = 10$

$\bar{\pi}$	Health expenditure	Health Expenditure % of Wage income	Health expenditure % of GDP	Survival Rate	Capital stock	GDP per Worker	GDP per capita	Welfare
Benchmark	0	0	0	0.20	0.24	5.63	4.69	4.88
0.1	0.21	5.14	3.08	0.24	0.37	6.71	5.39	5.34
0.2	0.47	9.31	5.59	0.32	0.66	8.47	6.42	6.06
0.3	0.71	11.50	6.90	0.40	1.09	10.34	7.37	6.78
0.4	0.92	12.66	7.59	0.49	1.63	12.16	8.18	7.44
0.5	1.11	13.26	7.95	0.57	2.28	13.90	8.83	8.03
0.6	***1.26***	***13.54***	***8.12***	***0.66***	***3.01***	***15.53***	***9.35***	***8.55***
0.7	1.39	13.64	8.18	0.75	3.79	17.04	9.74	9.01
0.8	1.50	13.62	8.20	0.84	4.60	18.42	10.03	9.41

Note: the reported variables in the table are defined as follows[10]

Health expenditure — h, Health expenditure % of Wage income — h/w, Health expenditure % of GDP — $h/f(k)$, Survival rate — $\pi(h)$, Capital stock — k, GDP per worker — $f(k)$, GDP per capita — $f(k)/(1+\pi(h))$, Welfare — $u(c_1)+\pi(h)u(c_2)$

[10] These definitions are the same in all tables in this section.

In addition, the third column in table 5-2 shows health expenditure to income ratio. This ratio can be thought as a kind of health tax levied by the government upon income, such as the income tax rate in national health insurance program in many countries. According to the data from WHO, in several high-income countries, such as Germany and USA, national health insurance program covers more than 2/3 of the population with a tax rate of 11%-14%. This is consistent with the simulation results in the third column, if we assume that national health sector provides most of the medical products and services and disregard the welfare effect of national health programs (for example, some forms of medical subsidies). When we come to the case of China, its health expenditure to GDP ratio (average value in recent 5 years is around 5.5%) and corresponding $\overline{\pi}$ value (about 0.18) are ranked in the middle income country group. The simulated health expenditure to income ratio of 9.3% is higher than 8%, the level that is jointly supplied by individuals and employers in current Urban Basic Medical Insurance. However, the current coverage of this social health insurance program is only about 10% (2006), and the private health expenditure accounts for as much as half of the total health expenditure. Some researchers, such as Tan (2005) and Wang (2004), suggest that the public health expenditure should play a more important role in national health improvement. Thus, the current tax rate is apparently underestimated if Urban Basic Medical Insurance tends to cover more people. Since we lack enough data for the worldwide national health programs and regarding that the operation of public health system is not the focus of this paper, we will not discuss this topic further.

5.3 Sensitivity test

We also carry out sensitivity test of the simulation results discussed above. Varying exogenous parameters within reasonably wide ranges of values yields similar results that differ only quantitatively. Therefore, we are reasonably convinced that our core analysis and results on the relationship between health investment and economic growth in the present paper are quite robust in the qualitative sense. Sensitivity test results are reported in Table 5-3. The sensitivity results with respect to π_0 may seem particularly interesting.

Incorporating endogenous health investment in our model, steady state values of GDP per worker, GDP per capita and welfare do not vary drastically as the state of innate health stock ranges from 0.1 to 0.3. Intuitively, supplementary health investments optimally evade the inherent health risk and keep the economic growth and welfare at a relative high level. On the other hand, without necessary supplementary health investment, innately low heath state (for example, in the present poorest countries) may probably drag the society into a poverty trap.

Note that while our model is capable of closely matching the empirical data on health expenditure to GDP ratio in Table 2-1and Table 2-2 under reasonable parameter values, the simulated survival rates in Table 5-2 are systematically lower than those in the former two tables. One plausible reason is that we only consider health expenditures of medical products and services but neglect other health-related factors such as personal life style, living environment, and international medical aids. In fact, various food and health aid programs provided by international organizations to poor countries have significant impact on the local mortality rate. It is not surprising to see that the underestimation of the survival rate in our simulation is more substantial in those low-income countries.

Table 5-3: Sensitivity test

1) Alternative value of α

Parameters: $\pi_0 = 0.2, \bar{\pi} = 0.6, \gamma = 0.5, A = 10$

α	Benchmark model ($\bar{\pi} = 0$)				Our model ($\bar{\pi} = 0.6$)			
	Survival rate	GDP per worker	GDP per capita	Welfare	Survival rate	GDP per worker	GDP per capita	Welfare
0.30	0.2	6.73	5.61	5.49	0.65	13.08	7.93	7.92
0.35	0.2	6.21	5.17	5.21	0.66	14.20	8.58	8.22
0.40	0.2	5.63	4.69	4.88	0.66	15.53	9.35	8.55
0.45	0.2	4.98	4.15	4.52	0.67	17.09	10.26	8.90
0.50	0.2	4.27	3.56	4.10	0.67	18.87	11.30	9.26

2) Alternative value of γ

Parameters: $\pi_0 = 0.2, \bar{\pi} = 0.6, \alpha = 0.4, A = 10$

γ	Benchmark model ($\bar{\pi} = 0$)				Our model ($\bar{\pi} = 0.6$)			
	Survival rate	GDP per worker	GDP per capita	Welfare	Survival rate	GDP per worker	GDP per capita	Welfare
0.1	0.2	7.88	6.57	6.68	0.65	17.97	10.90	11.31
0.3	0.2	6.64	5.53	5.27	0.65	16.59	10.04	9.30
0.5	0.2	5.63	4.69	4.88	0.66	15.53	9.35	8.55
0.7	0.2	4.78	3.98	5.81	0.68	14.58	8.68	9.59
0.9	0.2	4.07	3.39	13.35	0.71	12.80	7.47	19.99

3) Alternative value of A

Parameters: $\pi_0 = 0.2, \bar{\pi} = 0.6, \gamma = 0.5, \alpha = 0.4$

A	Benchmark model ($\bar{\pi} = 0$)				Our model ($\bar{\pi} = 0.6$)			
	Survival rate	GDP per worker	GDP per capita	Welfare	Survival rate	GDP per worker	GDP per capita	Welfare
5	0.2	1.77	1.48	2.74	0.56	4.17	2.68	4.30
10	0.2	5.63	4.69	4.88	0.66	15.53	9.35	8.55
15	0.2	11.05	9.21	6.85	0.70	32.38	19.02	12.52
20	0.2	17.84	14.87	8.70	0.72	53.92	31.29	16.29
25	0.2	25.87	21.56	10.47	0.74	79.71	15.90	19.92

4) Alternative value of π_0

Parameters: $A = 10, \bar{\pi} = 0.6, \gamma = 0.5, \alpha = 0.4$

π_0	Benchmark model ($\bar{\pi} = 0$)				Our model ($\bar{\pi} = 0.6$)			
	Survival rate	GDP per worker	GDP per capita	Welfare	Survival rate	GDP per worker	GDP per capita	Welfare
0.10	0.10	2.86	2.60	3.26	0.56	13.49	8.65	7.83
0.15	0.15	4.26	3.70	4.13	0.61	14.54	9.02	8.21
0.20	0.20	5.63	4.69	4.88	0.66	15.53	9.35	8.55
0.25	0.25	6.96	5.57	5.55	0.71	16.48	9.63	8.86
0.30	0.30	8.27	6.36	6.16	0.76	17.37	9.86	9.15

6. Concluding Remarks

Widespread empirical evidence and theoretical works, at both individual and aggregate levels, reveal a strong correlation between economic growth and health status or life expectancy. In this paper, we presented an overlapping-generation model with production (Diamond 1965) modified to include endogenous longevity risk, and examined the inter-dependence between health investment and economic development in a general equilibrium framework. We showed in our model that optimal health investment and savings are complements in that they rise and fall together along a development path.

Compared to the benchmark model with a constant exogenous survival probability, our simulation showed that, the optimal health expenditure is growth-promoting as well as welfare-improving. The impact of health investment on economic growth is particularly meaningful because it exists in the context where health investment brings a higher life expectancy and hence entails higher dependency ratio induced by potential population ageing. Therefore, in the light that China is experiencing a rapid population ageing process, it is suggestible to pay more attention to the accumulation of health capital by increasing health expenditure especially the health investment from the public sector. Furthermore, our findings are consistent with several stylized facts observed in the data, where countries with higher income spend more on health improvement and have on average higher life expectancy.

However, there are two ways to get a better gauge of the importance of health. One approach is to use cross-country evidence and more sophisticated econometric methods, as is used in McGrattan and Schmitz's (1998) analysis of cross-country growth or Kalemli-Ozcan et al.'s (2000) study of the effects of (exogenous) mortality decline. The other way is, to better quantify the contribution of health investment in China, we need a more complicated overlapping-generation model to project the economic growth with adequate time series data as Suen (2005) did. As a preliminary pass to formally analyze the role of health capital, we utilized a very simple neoclassical model in the present paper. We disregarded several other health-related factors that could affect economic growth significantly, such as labour efficiency, working years and the impact of parents' health capital accumulation on children. Indeed, we still have a long way ahead.

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Appendix 1: Individual Saving and Health Investment

Ignoring the time subscript, equation (15) gives:

$$\pi'(h)u(\frac{sf'(s)}{\pi(h)}) = \pi(h)u'(\frac{sf'(s)}{\pi(h)})f'(s)$$

Differentiating both sides of the above equation with respect to m and denoting $c = c_{t+1} = \dfrac{sf'(s)}{\pi(h)}$, we have:

$$\pi''(h)u(c) + \pi'(h)u'(c)\left[\frac{f'(s)+sf''(s)}{\pi(h)}\frac{ds}{dh} - \frac{\pi'(h)sf'(s)}{\pi(h)^2}\right]$$

$$= \pi'(h)u'(c)f'(s) + \pi(h)\left[u''(c)f'(s)\frac{f'(s)+sf''(s)}{\pi(h)}\frac{ds}{dh} - \frac{\pi'(h)sf'(s)}{\pi(h)^2}) + u'(c)f''(s)\frac{ds}{dh}\right]$$

Rearranging the above equation, we have:

$$\pi'(h)u'(c)f'(s) - u''(c)sf'(s)^2\frac{\pi'(h)}{\pi(h)} - \pi''(h)u(c) + u'(c)sf'(s)\frac{\pi'(h)^2}{\pi(h)^2}$$

$$= \left[(\pi'(h)u'(c) - \pi(h)u''(c)f'(s))(\frac{f'(s)+sf''(s)}{\pi(h)}) - u'(c)f''(s)\right]\frac{ds}{dh}$$

As is shown in the footnote 4, we have $f'(k) + kf''(k) > 0$ for a Cobb-Douglas product function. $f(\cdot)$, $u(\cdot)$ and $\pi(\cdot)$ are all increasing and concave functions. It means $\dfrac{ds}{dh} > 0$ because LHS and the part in the bracket of the above equation are both greater than zero.

Appendix 2: Health Investment and Capital Stock

We can't get the direct relationship between capital and health investment using normal differentiation, however, we can solve it by way of reduction to absurdity:

Inserting (22) into (23), it yields:

$$\frac{1}{\left[f(k_t) - k_t f'(k_t) - s_t - h_t \right]^{\gamma}} = \pi(h_t)^{1+\gamma} s(h_t)^{-\gamma} f'(s(h_t))^{1-\gamma}$$

$$= (\alpha A)^{1-\gamma} \pi(h_t)^{1+\gamma} s(h_t)^{-\gamma} s(h_t)^{(\alpha-1)(1-\gamma)}$$

$$= (\alpha A)^{1-\gamma} \pi(h_t)^{1+\gamma} s(h_t)^{\alpha(1-\gamma)-1}$$

$$= \frac{(\alpha A)^{1-\gamma}}{(1-\gamma)^{1-\alpha(1-\gamma)}} \cdot \frac{\pi'(h_t)^{1-\alpha(1-\gamma)}}{\pi(h_t)^{(1-2\alpha)(1-\gamma)}}$$

Suppose that k_t rises and h_t (thus s_t) falls, on the left hand side, the denominator will increase thus LHS will decrease. On the right hand side, with $\alpha < 1/2$ as is shown in many empirical works (e.g. Mankiw, Romer and Weil 1992) and $0 < \gamma, \alpha < 1$, the numerator decreases but the denominator increases, RHS will increase. It is a contradiction to our initial presumption, so that k_t and h_t are positively related.

Appendix 3: Solutions to Steady State Capital

Parameter: $0 < \gamma, \alpha < 1$

1. Steady state without health investment

Because the steady state is characterized by $s_t = k_t = k = s$ and $h_t = h$, in addition to $f(k) = Ak^{\alpha}$, equation (30) can be rewritten as:

$$[f(k) - kf'(k) - k]^{-\gamma} = [(1-\alpha)Ak^{\alpha} - k]^{-\gamma} = \pi_0^{1+\gamma}(A\alpha k^{\alpha-1})^{1-\gamma} k^{\gamma}$$

$$\Rightarrow \frac{A(1-\alpha)k^{\alpha} - k}{(A\alpha)^{\frac{\gamma-1}{\gamma}} k^{\frac{(\alpha-1)(\gamma-1)}{\gamma}+1}} = \pi_0^{-\frac{\gamma-1}{\gamma}}$$

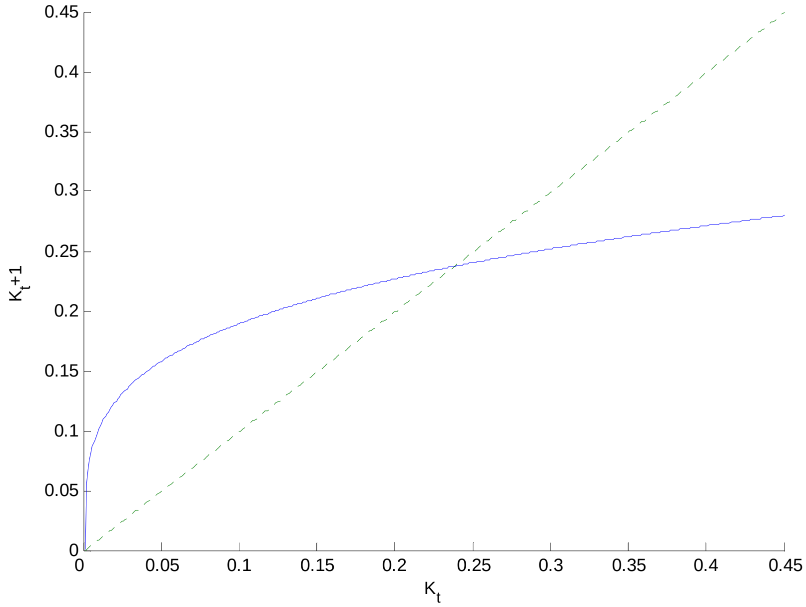
Define the LHS of the above equation as $J(k)$, and denote the RHS as C (>0).

Since $J(k) = \frac{1}{(A\alpha)^{\frac{\gamma-1}{\gamma}}}[A(1-\alpha)k^{\frac{\alpha-1}{\gamma}} - k^{\frac{(\alpha-1)(1-\gamma)}{\gamma}}] = \frac{1}{(A\alpha)^{\frac{\gamma-1}{\gamma}}} k^{\frac{\alpha-1}{\gamma}}[A(1-\alpha) - k^{1-\alpha}] = C$, we have:

$\lim_{k\to 0} J(k) = \infty$, $\lim_{k\to\infty} J(k) = 0$ and $J(k)$ is monotonically decreasing in k. We can confirm there is a unique k^* for $J(k) = C$.

When the utility takes a log form (a special case of CRRA utility), it is convenient to prove that there exists only one non-trivial steady state. We do not prove it for the case of our utility shape, but simulate the law of the motion for k_{t+1} in the following figure with the parameters used in our base case (see simulation part). Obviously, the intersection shown in the figure is the unique stable steady state.

Figure 1: Dynamics without health investment



2. Steady state with health investment

Because the steady state is characterized by $s_t = k_t = k = s$ and $h_t = h$, in addition to $f(k) = Ak^{\alpha}$, equation (23) can be rewritten as:

$$[f(k) - kf'(k) - k - h]^{-\gamma} = [(1-\alpha)Ak^{\alpha} - k - h]^{-\gamma} = \pi(h)^{1+\gamma}(A\alpha k^{\alpha-1})^{1-\gamma}k^{\gamma}$$

$$\Rightarrow \frac{A(1-\alpha)k^{\alpha} - k - h}{(A\alpha)^{\frac{\gamma-1}{\gamma}}k^{\frac{(\alpha-1)(\gamma-1)}{\gamma}+1}} = \pi(h)^{-\frac{\gamma-1}{\gamma}}$$

Define the LHS of the above equation as $P(h)$, and define the RHS as $J(h) > 0$, we have:

$$P(k) = \frac{1}{(A\alpha)^{\frac{\gamma-1}{\gamma}}}[A(1-\alpha)k^{\frac{\alpha-1}{\gamma}} - k^{\frac{(\alpha-1)(1-\gamma)}{\gamma}} - k^{\frac{\alpha-1}{\gamma}-\alpha}h] = J(h)$$

At steady state, from equation (18), we get $k(h) = \dfrac{(1-\gamma)(\pi_0 + \bar{\pi}\sqrt{\frac{h}{1+h}})^2}{\frac{\bar{\pi}}{2}\sqrt{\frac{1+h}{h}}(\frac{1}{1+h})^2}$.

$$\lim_{h\to+\infty} k(h) = \lim_{h\to+\infty} \frac{2(1-\gamma)(\pi_0 + \bar{\pi})^2(1+h)^2}{\bar{\pi}} \sim \lim_{h\to+\infty} \frac{2(1-\gamma)(\pi_0 + \bar{\pi})^2 h^2}{\bar{\pi}}$$

$$\lim_{h\to+\infty} k(h) = \lim_{h\to+\infty} Bh^2 \text{ with } B = \frac{2(1-\gamma)(\pi_0 + \bar{\pi})^2}{\bar{\pi}}$$

$$\lim_{h\to+\infty} P(k(h)) = \lim_{h\to+\infty} \frac{1}{(A\alpha)^{\frac{\gamma-1}{\gamma}}}[A(1-\alpha)(Bh)^{\frac{2(\alpha-1)}{\gamma}} - (Bh)^{\frac{2(\alpha-1)(1-\gamma)}{\gamma}} - B^{2(\frac{\alpha-1}{\gamma}-\alpha)}h^{\frac{\alpha-1}{\gamma}-a+\frac{(\alpha-1)(1-\gamma)}{\gamma}}] = 0$$

$$\lim_{h\to 0} k(h) = \lim_{h\to 0} \frac{2(1-\gamma)\pi_0^2}{\bar{p}\sqrt{\frac{1+h}{h}}} \sim \lim_{h\to 0} \frac{2(1-\gamma)\pi_0^2}{\bar{\pi}} h^{\frac{1}{2}}$$

$$\lim_{h\to 0} k(h) = \lim_{h\to 0} Ch^{\frac{1}{2}} \ \text{ with } C = \frac{2(1-\gamma)\pi_0^2}{\bar{\pi}}$$

$$\lim_{h\to 0} H(k(m)) = \lim_{h\to 0} \frac{1}{(A\alpha)^{\frac{\gamma-1}{\gamma}}} (Ch^{\frac{1}{2}})^{\frac{\alpha-1}{\gamma}} [A(1-\alpha) - (Ch^{\frac{1}{2}})^{1-\alpha} - (Ch^{\frac{1}{2}})^{-\alpha} h]$$

$$= \lim_{h\to 0} \frac{1}{(A\alpha)^{\frac{\gamma-1}{\gamma}}} (Ch^{\frac{1}{2}})^{\frac{\alpha-1}{\gamma}} [A(1-\alpha) - (Ch^{\frac{1}{2}})^{1-\alpha} - C^{-\alpha} h^{1-\frac{\alpha}{2}}] = +\infty$$

Since $J(h)$ is bounded in h and positive, we can confirm the existence of solutions for $P(k(h)) = J(h)$. Unfortunately, we are not able to prove the monotonies of $P(k(h))$. However, with a set of parameters we use in the base case simulation, the following figure shows that $P(k(h))$ and $J(h)$ intersect only once within a large-enough interval. And the sensitivity test shows that simulation results are robust in a relatively small interval. See also the simulated transition path of k_{t+1} and h_t in Figure 3.

Figure 2: Intersection of $P(k(h))$ and $J(h)$

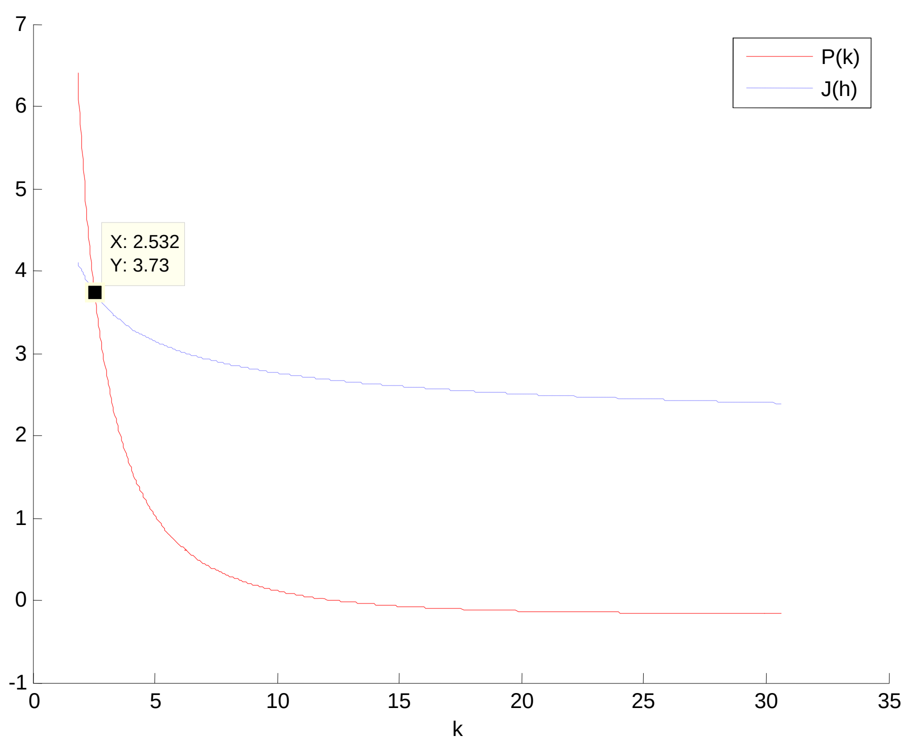


Figure 3: Dynamics with health investment